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Green accounting for greener energy

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ABSTRACT

The first step towards the widespread use of renewable energy sources and preservation of our environment for the people of the future is to adopt the "green accounting" standards that translate socially and environmentally responsible behavior into monetary terms, the only language businesses understand. These standards have the potential of switching on the red light for all pollution-causing power plants, and those depleting the natural capital in any way, be it over-harvesting the forests, or exhausting the underground treasures – coal, oil, natural gas, etc. This paper will show how green accounting can help in changing the focus from the economic welfare to the total societal welfare, acknowledging the fact that human society is an integral part of the natural world. The paper will also briefly present the software developed by the authors that introduce the green accounting principles into the investment appraisal process, aiming at encouraging investments into renewable energy. The tool is also useful as a platform facilitating calibration of economic/financial instruments, like environmental taxes of governmental incentives, that are usually to boost renewable energy sector. The comparative analysis of investment into biofuel-powered combined heat and power production plant using two types of investment valuation standards, one based on conventional cash-flow analysis, the other based on green-accounting standards is detailed in the paper. The analysis is performed as a part of the European Commission Framework Program Project AFTUR, undertaken by the consortium consisting of respectful European Research Establishments in renewable energy area as well as major European biofuel-powered turbine producers. The results show that the wider adoption of green accounting standards would induce the unprecedented growth of the renewable energy sector, because it would make the investment into renewable energy attractive for investors.

Contents

1. Introduction

While the considerable attention has been paid to the standardization in the technical domain, especially regarding the interconnection of the renewable energy sources to the utility grid [1–4] there is almost total neglect of equally important economic/financial standardization that would motivate more

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widespread use of renewable energy sources. However, there is a wide recognition of natural capital depletion problem, and fossil fuels being one of its major causes. "According to the energy scientists, increasing energy usage coupled with the depleting natural resources to generate energy will cause a large supply to demand discrepancy in near future. The best answer to that crisis will be the use of renewable energy. Unlike fossil fuels, the renewable sources are sustainable. The use of renewable energy technologies today will not only benefit us now, but will benefit many generations to come" [5]. However, the wide awareness of the sustainability of renewable energy sources is not sufficient to motivate their wider use as long as they are less cost effective, which they definitely are if we use current accounting standards and cost benefit analysis that does not take into account the changes in natural systems. Even worse, if they are taken into account, they are put on the wrong side of the balance sheet (see Section 2). In any socially and environmentally responsible accounting for "how well we are doing," changes in natural systems should be evaluated as well as commercial ones.

After having witnessed countless ecological disasters and the progressive degradation of the earth's ecosystems, society is beginning to ask for the environmentally responsible behavior on the part of both government and businesses. Of course, if business managers are left alone to solve the ethical dilemma – to make a profit or to preserve the environment, the result would be rather predictable. Therefore, there should be a standardized, quantitative way to hold the businesses accountable for polluting and destroying our environment that goes beyond environmental taxation or forcing industries to clean-up what they polluted. Most of the damages are irreversible, i.e. they cannot be "undone" so they should be prevented instead. One way of doing this is by introducing so-called "green" (environmental) accounting, a system in which financial and economic measurements take into account the effects of power production and consumption on the environment. This way, any power plant that damages critical natural capital, especially the irreplaceable one, is accounted for it. When environmental stewardship is expressed in monetary terms – the only language businesses understand, the above mentioned ethical dilemma has some chances to be solved to the benefit of the society as a whole.

Therefore, the "green accounting" should be introduced urgently, as nicely put by British Prince Charles in his speech at the Institute of Chartered Accountants when he said: "*Your profession is one of the key pillars of our economic stability and prosperity, but to ensure that our descendants can experience something of prosperity there is a very real urgency to adapt our accounting procedures to the critical challenge of minimizing the wasteful damage done to the fragile world around us through man's increasingly short-term perspective*." [6].

The standard accounting system has indeed this short-term perspective, as Prince Charles has put it. Therefore, unless broader and longer-term environmental and social factors are considered more effectively in accounting, what we enjoy today will be at the expense of our children and grandchildren. Society must be able to hold power plants accountable for their environmental impact, and for this to happen, it is essential that communities can access information about the environmental impact of their activities. The best way to do this is to express this impact in the monetary terms so that it appears in the balance sheets. When we attach price to pollution rates and to the irreplaceable natural capital consumption (be it coal, oil or natural gas), it will then become visible on the business radar and disclosed to the wider public sooner or later. This is only possible if the "green accounting" becomes widely adopted. And if we look at Fig. 1 bellow, taken from the World Bank report [7], we will see how critical the state of the Natural capital in

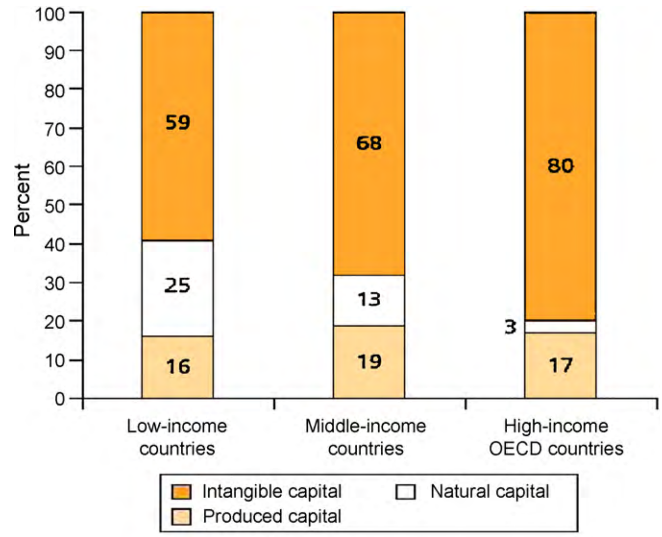


Fig. 1. Natural capital depletion (Source: World Bank [7]).

the high income countries already is (only 3% of total capital). It is, therefore, easy to conclude that the red light for polluters should be switched on immediately, and it could be done by the "green accounting" only.

The most effective measures are the preventive ones that actually discourage the start-up of businesses that could further damage the Natural capital. This could be done introducing the "green accounting" in the phase of the investment project appraisal and business plan preparation for a new power plant. When the investment projects are prepared in conventional way, using traditional cash-flow analysis, the environment protection costs are usually assumed not to affect significantly a new factory's operations [8,9]. Both owners and managers emphasize profitability indicators, like the return of investment period, breakeven point, internal rate of return, etc., which is easy to understand. It is only normal for them to wish for the investment to pay off as soon as possible, and if they invest in cheaper "non-green" technologies and cheaper "non-green" energy sources, like fossil fuels, it will happen sooner. However, if the "green accounting" is used that penalizes for the damage done by using cheaper "non-green" fossil fuels, investors might actually conclude that the greener energy sources actually pay off in longer terms.

When the "green accounting" is used, it is necessary to identify and quantify the environmental impact of the investment project and the cost of annulating this impact (soil remediation, water purification, and other clean-up action), not to mention irreversible damage to the environment and human health. Without these calculations, investment managers may make very "expensive" wrong decisions, especially from the perspective of future generations. The costs treated by the standard accounting are insufficient if the environmental and social responsibility is considered. And they should be considered, because power plants do not operate in a vacuum. They operate in the environment from which they irreversible take the energy sources (non-renewable ones like fossil fuels), and they operate in a community from which they borrow their work force and which may also be impacted by their operations. Standard accounting reflects a fantasy economics that assumes an infinite supply of non-renewable raw materials and zero costs associated with the consumption and disposal of goods. Non-renewable resources like crude oil follow a bell shaped supply curve. During the easy to find and extract "up" side of bell curve, supply out-strips demand and prices are low. In most minds supply and reserves are thought to infinite and no thought is given

to conservation. Indirect costs like pollution, suburban sprawl, energy insecurity, and climate change are not translated into monetary terms and factored into the price, but are paid none the less through higher healthcare costs, lower productivity, taxes, and "natural" disasters. "Green accounting", however, factors all this indirect effect into costs and therefore proves to be the most effective way of addressing these challenges [10].

To show how the perspective changes dramatically when we use green (environmental) accounting instead of standard accounting in investment project appraisal, we will use an illustrative example of biofuel-powered combined heat and power generation plant. The economic and financial indicators that are crucial to boost an investment into renewable energy sources change significantly. Both analysis are performed using software packages developed by the authors [8,9], and are therefore completely unbiased. If we further combine these indicators to other sustainability indicators, like social, environmental, technological, using the multi-criteria analysis platform using outranking methodology (also developed by the authors), the results will be further in favor of renewables.

The paper is structured as follows. Section 2 describes the basic principles of environmental (green accounting) and shows how erroneous the standard accounting can be from both corporate and national point of view. In Section 3 we will briefly describe a web-based decision support system, developed by the authors of this paper, that actually enables investment project evaluation and appraisal using green accounting principles. In Section 4 we have provided the results of an ordinary financial appraisal for industrial-scale CHP plants using different fossil and bio-fuels. Section 5 describes the effects of applying the principles of "green accounting" on the profitability and ranking of analyzed CHP plants. In Section 6 we have performed a socio/economic analysis based on the demand side effects. In Section 7 we have presented the results of Multi-Criteria Analysis (MCA) applied on various CHP plants using different fossil and bio-fuels based on 44 technological, financial, socio/economic and environmental criteria. Section 8 contains a brief summary of all results, while Section 9 presents the conclusions.

2. Environment on the wrong side of the balance sheet

"*Green or environmental accounting describes an effort to incorporate environmental benefits and costs into economic decision making.*" – *Gernot Wagner* [11]

Green accounting induces some rather sensitive issues, since it significantly influences the cost effectiveness of the operations, which is main corporate concern. Many attempts to monetarize environmental impacts seriously underestimated the significance of these issues relative to the economic issues [12]. Therefore, a corporate "green accounting" should be precisely regulated and standardized in the same way as the old fashioned accounting was. For that to be done, the academic accounting community has a responsibility to reach consensus among all affected stakeholders regarding how accounting and organizational management can fulfill their responsibilities towards our environment and our society as a whole [13].

While corporate "green" accounting is concerned with business' environmental impact, national "green" accounting should try to accomplish the same on a country level. When we speak about the national level, than the Gross Domestic Product (GDP) is by far the most important economic indicator, and it is often considered to be a measure of national welfare. While the GDP does a rather good job of estimating the size of our economy, it is completely inadequate as true welfare measure. Not only that it ignores our environment completely, but even worse, it often includes the environment on the wrong side of the balance sheet. If we first pollute and then pay to clean up the pollution, both activities actually add to GDP.

Environmental degradation frequently looks good for the economy, which is absurd that could be illustrated with simple examples. A huge Exxon Valdez oil spill in Alaska, actually posted gains to the GDP, because the additional costs of the clean-up are added to GDP instead of being subtracted, what would have been expected. Similarly, when a paper mill dumps dangerous chemical wastes into a river, the paper-making boosts GDP, but no deduction is made for the costs associated with water pollution. Again, water remediation and purification activities are added to the GDP. GDP actually shows measures to tackle pollution as bonuses, not as burdens. An imaginary country that would cut down all its forests, sell the trees as wood chips and gamble away all the money, would appear from its national accounts to have become richer in terms of GDP per capita. If Brazil cuts down its entire rainforest and sells off its trees this year, GDP would jump up enormously, because the market value of all those trees gets added to GDP. But nobody subtracts the fact that those trees are no longer there. With green accounting we could determine the economic value of these trees, since they produce oxygen, purify air and water, provide watershed protection, prevent soil erosion, etc.

Similarly, as professor Davis from the Colorado School of Mines said in his radio interview, "*Every time we mine a ton of coal, GDP goes up by $17 a ton, but that doesn't take into account the fact that we've harvested one ton of coal from the Earth and that ton of coal is no longer there and will never be there again. The green accounting would add in depletion, and when you do that, the numbers start to change. The value to society of that ton of coal in GDP terms would be about $17 for West Virginia coal. In green income terms, it would be about 5 Dollars and 50 cents*". And this adjustment only accounts for the decrease of coal as the underground asset. It does not consider a more important human cost. If the medical bills of all those miners that suffer from black lung disease or hearing loss are subtracted from the economic value of the coal, the price would be even lower. Paradoxically, the illness of the coal miners actually adds to the GDP as well as the cost of cleaning up abandoned mines and remediating the polluted environment. All these environmental costs appear on the wrong side of the balance sheet, and make the environmental degradation look good for the economy. How ethical?! Therefore, both corporate and national accounting systems need their own Copernican revolution!

Too long accountants have been turning the blind eye to the real world affairs, the substance of which is their business to capture [14]. The accountants are actually the best equipped to help businesses to play their roles in reducing the greenhouse gases and other pollutants pouring into the environment. They should include the value of diminishing natural resources, and the cost of increasing atmospheric pollution, into the price of what we buy and consume! At the moment, these costs often do not appear in anyone's books, or even if they do, they appear on the wrong side as shown above. Therefore, the cost of destroying a rainforest or pumping tons of carbon into the atmosphere seems to be zero. Almost all of these costs, for which future generations will pay dearly, are given no value in accounts. They should be given value in both corporate and national accounts and this value should be visible not only in financial reports that appear on business radars, but also to the overall community. Indeed, it is our society as a whole that should hold both businesses and governments accountable for damage that they cause to our environment. For the moment, relying on GDP as the only measure of our well being, while it is only a measure of our economic output. GDP does not measure non-market goods and services. That's where the "green

accounting" work comes in. It does not have anything to do with being green or being environmental, or being anti- or pro-industry. It's simply good economics: accounting for all inputs, including our environment. We account for how much labor is out there in the economy. We account for machines and other capital. But one big item missing from our accounts is natural capital. Green accounting assumes that, in addition to having capital and labor accounts, there should be accounts for the natural capital: forests, subsoil assets, clean water and air, etc. Green accounting provides the means of measuring the impact of economic activities on natural capital that we all need desperately. "Millennium Development Goals are about creating wealth. If we don't measure it right, we won't manage it right," warned World Bank Vice President for Sustainable Development Ian Johnson, at the launch of "Where is the Wealth of Nations? Measuring Capital in the 21st Century" on the eve of the 2005 World Summit. According to the report from this Summit, governments and international organizations must begin to calculate natural resource depletion, among other factors, if a more complete vision of a country's wealth is to be established and if the environmental costs of development decisions are to be fully understood. Streamlining the accounting of resource depletion is also an aim of the United Nations, which is setting up a commission on environmental accounting and aims to have a universally accepted standard by 2010.

Obviously we need the green accounting urgently, but we also need a new set of incentives, a new awareness and a completely new kind of human behavior, if we want to preserve our environment for the future generations. The ethical dilemma, *profit or environment* (*i.e. future generations*), exist only in minds of short-sighted, greedy businessmen. Those that have broader views and longer-term visions have no dilemma whatsoever – we should preserve our environment for the future generations. "Leaders of high-commitment, high-performance organizations, refuse to choose between people and profits" [15].

3. Investment projects evaluation using green accounting standards

In the investment projects evaluation and appraisal, it is often assumed that environmental costs are not crucial to the operation of a new plant. However, now that the environmental standards are more severe, it often happens that some production costs have a significant environmental component, which is underestimated or neglected by investment analysts. For instance, the purchase price paid for the unused portion of crude oil in power plant that is emitted into air or discharged into the waste water, is usually not recognized as an environmentally related cost. These costs tend to be much higher than initially estimated and should be controlled and minimized and the best way to do it is to use the greener energy sources.

In the standard cash-flow analysis investment projects are appraised according to different profitability indicators, like net present value (NPV), internal rate of return (IRR) or payback period. In case of environment-related projects recognizing and quantifying environmental costs and benefits is both invaluable and necessary for the profitability assessment of the project. Without these calculations, investment decision makers may come to a false, irreversible and costly decision. To prevent such an irresponsible decision making, we have developed the decision support tool for investment project appraisal based on green accounting principles. It is called PEGAS (*P*roject *E*valuation *U*sing *G*reen *A*ccounting *S*ystem) and a screen shot of the software in operation are given in Fig. 2.

In the investment project analysis hidden, contingent and image costs should be also taken into account. The costs stated in standard methodologies are insufficient to provide an accurate estimation of the profitability and involved investment risks. Many cost items related to environmental management and protection must be included in the project appraisal. Generally, these costs may be grouped into five categories:

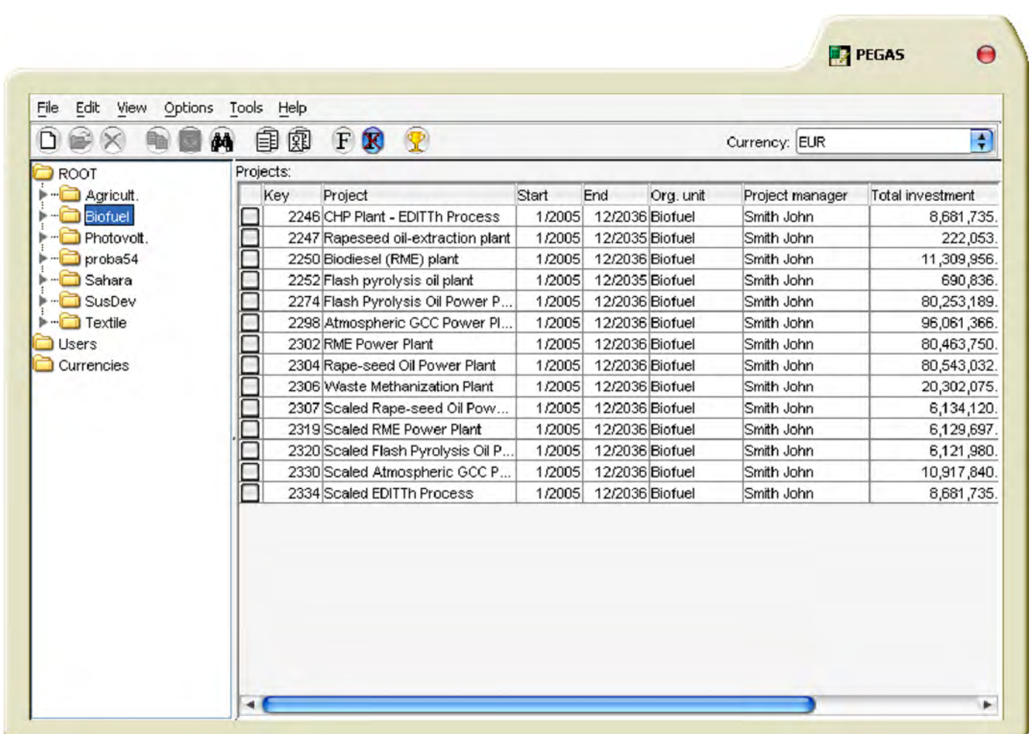


Fig. 2. PEGAS assessing investments into biofuel CHP plant.

- *Environmental portion of raw materials, utilities, labor and capital costs*. Although these costs are conventional costs which are always taken into account during investment project analysis, the environmental portion of these costs, e.g. non-product raw material costs, are not isolated and recognized as environmental.
- *Hidden administrative costs*. Some costs like monitoring, reporting or training costs are usually underestimated and buried in other administrative costs.
- *Future contingency costs*. These costs, related to possible clean-up or recovery costs and fines, are hard to predict and very often they represent a major business risk for the company.
- *Image benefits and costs*. These are the so-called intangible or "good-will" benefits and costs, which arise from the improved or impaired perception of stakeholders (environmentalists, regulators, customers, etc.)
- *External costs*. These costs are commonly not taken directly into account when making project decisions. However, the investment managers should be aware that high levels of external costs may eventually become internalized through stricter environmental regulation, taxes or fees.

PEGAS is a Web-based tool aimed at helping investment managers to take into account all these environmental related costs and benefits in investment project analysis and appraisal. It provides the standard cash-flow analysis based on the UNIDO methodology, sensitivity and risk analysis as well as support for multi-criteria decision making for selecting the best investment alternatives based on more than 30 static, dynamic and risk criteria.

All the capability of the software will be used to compare the investment appraisal results when both standard and green accounting principles are used. The case study is based on the biofuel-powered combined heat and power (CHP) generation plant. Since the tool is capable to simultaneously take into account all sorts of sustainability criteria (technological, economic, financial, environmental, social) it is easy to perform the sensitivity analysis changing perspectives and relative preferences among criteria. It is also a platform for consensus reaching among different stakeholders, having sometimes not only different, but also conflicting criteria. For instance, an investor would most certainly be more interested for the microeconomic effects and profitability of the proposed CHP plant, a policy maker would be interested more for the demand-side and other socio/economic effects as well as for the efficient implementation of environmental protection policy, while an environmentalist would be primarily interested for the environmental pollution issues.

Since our main concern in this paper is to provide standardized means for comparing CHP production using various fossil and biofuels, we have performed all feasibility studies and the evaluation of demand side effects for an industrial-scale CHP plant (18.6 MW), because biofuels of interest are still not available on the market in the quantities needed for a large-scale CHP production. However, it was impossible to find the reliable input data for different, industrial-scale CHP plants, so we had to scale-up or down (using the 0.9 rule) the investment and operation costs found for real-life examples.

4. Investment into CHP appraisal using conventional discounted cash-flow methodology

From the standpoint of investors into future CHP plant, the microeconomic effects are of the utmost importance. To explore these microeconomic effects, *FIDES* (*F*ramework for *I*nvestment *DE*cision *S*upport) has been used. FIDES [8] enables the decentralized creation, analysis and appraisal of investment projects (Fig. 3). As a basis for the investment project appraisal and the preparation of feasibility studies, the standardized methodology of the United Nations Industrial Development Organization has been chosen [16]. The methodology is based on modifications of

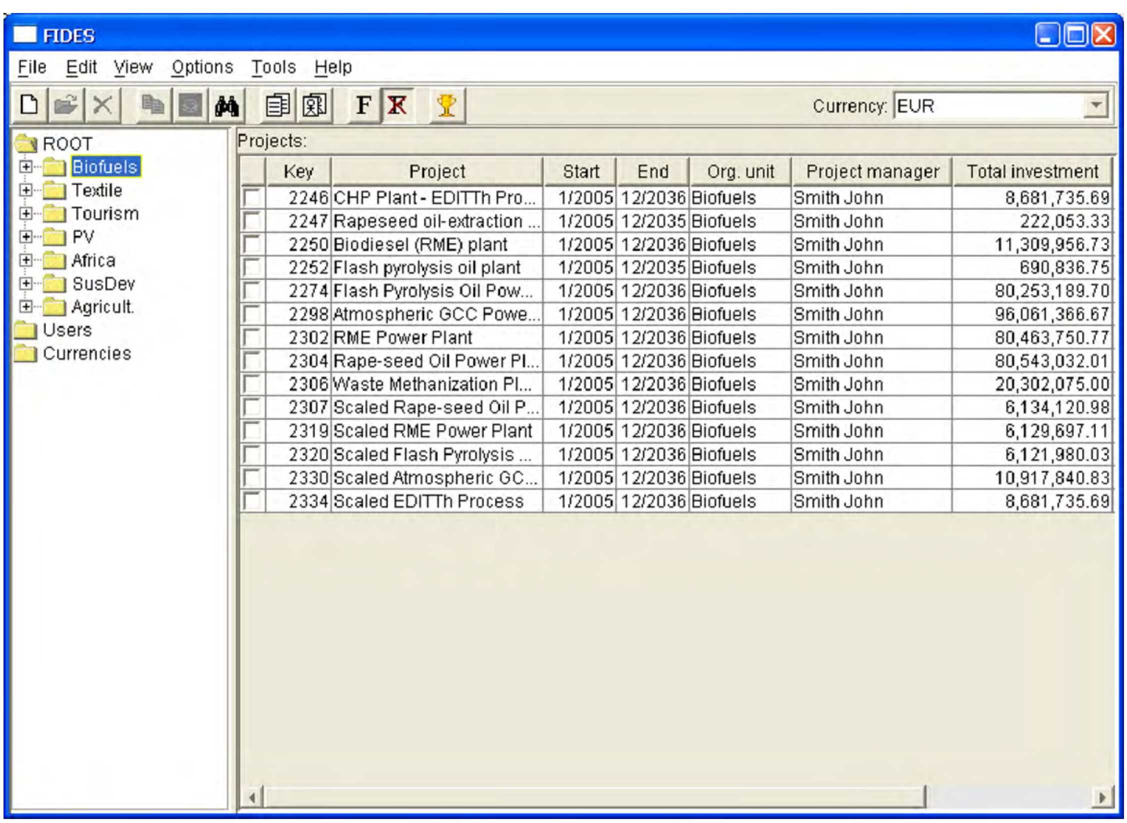


Fig. 3. FIDES screen-shot.

integrated standard analytical tables, where financial analysis is based on discounted cash-flow values. FIDES supports financial analysis, sensitivity analysis, risk analysis and multi-criteria decision-making to identify the best investment options based on more than thirty static, dynamic and risk indicators.

Using FIDES, we have firstly performed the appraisal of the investment into heat and power cogeneration using different liquid befouls, like vegetable oils, rape-seed methyl ether (RME) and flash pyrolysis oil, CHP plants that use these liquid biofuels and naphtha as well as well as for the CHP plants using gasification from wood, gasification from coal, slow pyrolysis (EDDITh) processes, waste methanization and Combine Cycle Gas Turbine (CCGT) using natural gas.

To assess the microeconomic effects of different biofuels, used later to evaluate the demand side economic effects, several feasibility studies have been performed. The feasibility study for the rape-seed oil extraction plant is based on information found in [17], the study for the production of flash pyrolysis oils is based on information provided by Laboratory of Thermal Engineering, University of Twente, while the study for the RME production plant is based on data found in [18] and data provided by Institut Français du Pétrole.

The feasibility study for the rape-seed oil extraction plant has been performed for a small plant with the capacity of 750 tone of rape-seed oil and 1550 tone of cake per annum. The construction phase takes 1 year, and the plant will operate 30 years. The total investment costs for this extraction plant are estimated at 174,500 €. The price of rape-seed is taken to be 300 €/t [19]. The investment costs are financed by a 20-year long-term loan with constant principal and 5.5% interest. The price of rape-seed oil is taken to be 614 €/t [20] and the price of cake – 180 €/t [21].

The feasibility study for the RME production plant has been performed for a large plant with the capacity of 100,000 tone of biodiesel and 10,432 tone of high quality glycerin per year. The duration of construction is 2 years, and the production phase takes 30 years. The total investment costs for this plant are estimated at 6,250,400 €. The price of rape-seed oil is taken to be 614 €/t, the price of biodiesel is 725 €/t [20], and the price of glycerin is 350 €/t [22]. The investment costs are financed by a 20-year long-term loan with constant principal, 2 years grace period and 5.5% interest.

The feasibility study for the production flash pyrolysis oils has been performed for a plant with the capacity of 2000 tons per annum. The construction phase takes 1 year, and the operating life is 30 years. The total investment costs are estimated at 674,400 €. The plant is operating using residuals from the forestry industry at price of 40 €/t. The price of flash pyrolysis oil is taken to be 161.29 €/t [23]. The investment costs are financed by a 20-year long-term loan with constant principal and 5.5% interest.

Some basic data from these three feasibility studies are summarized and presented in Table 1.

The dynamic indicators of liquid biofuel production efficiency at 12% discount rate are presented in Table 2. Financially, the most efficient is the flash pyrolysis oil production, then RME production, and, at last, rape-seed oil production.

For the feasibility studies for CHP plants using different liquid biofuels data found in [24] and [25] have been used. The 100 MW_e CHP plant has the heat to power ratio of 2 and 90% of heat and power efficiency. The costs of this plant are then scaled down to the size of industrial-scale CHP plant. The feasibility studies have been performed for the same plant using different liquid fossil and biofuels. The construction phase takes 2 years and operating life is 30 years for all plants. For the financing of investment costs a 20 years long-term loan is used with constant principal, 4 years grace period and 5.5% interest. The price of electricity is 13 c/kWh [26], while the price of thermal power is 3 c/kWh [27].

Table 1
Liquid biofuel production – basic data.

Parameter	Rape-seed oil	RME	Flash pyrolysis oil
Capacity (tone/year)	750	100,000	2000
Construction (years)	1	2	1
Operating life (years)	30	30	30
Investment costs (€)	174,500	6,250,400	674,400
Biofuel price (€/t)	614	725	161
Biofuel price (c/l)	56	64	20

Table 2
Dynamic indicators of liquid biofuel production.

Indicator	Rape-seed oil	RME	Flash pyrolysis oil
Net present value (€)	95,465.11	30,729,001.40	78,433.60
Internal rate of return (%)	18.57	55.84	13.65
Normal payback (years)	6	3	7
Dynamic payback (years)	9	4	17
Relative NPV	0.55	4.92	0.12
Critical point (years)	2	3	2

The total investment costs for a rape-seed oil CHP plant are 6,582,885.55 €, total operating costs are 7,559,591.96 € with rape-seed oil costs representing the main part of operating costs. The CHP plant spends 11,741 tons per annum of rape-seed oil at price of 614 €/t.

The total investment costs for RME CHP plant are 6,697,172.78 €, while operating costs are 8,806,361.75 € with biodiesel costs representing the major part of operating costs. The CHP plant is using 11,663 tons per year of biodiesel at price of 725 €/t.

The total investment costs for a CHP plant using flash pyrolysis oils are 6,358,034.64 €, total operating costs are 5,106,673.00 € with flash pyrolysis oil costs representing the main part of operating costs. The CHP plant is using 29,486 tons per year of flash pyrolysis oil at 161,29 €/t.

The total investment costs for a naphtha CHP plant are 6,316,368.02 €, while operating costs are 4,652,128.00 €, where costs for naphtha represent the major part of operating costs. The CHP plant is using 9558 tons per year of naphtha at price of 450 €/t.

Some basic data from the three feasibility studies for CHP plants using liquid fossil and bio-fuels are summarized and presented in Table 3.

The dynamic indicators of liquid biofuel production efficiency at 12% discount rate are presented in Table 4. For the given prices of electricity and thermal power, the rape-seed oil CHP plant is efficient, biodiesel (RME) CHP plant is not profitable, while flash pyrolysis oil and naphtha CHP plants are very efficient.

The feasibility study for the combined heat and power generation using the slow pyrolysis (EDDITh process, plant size 18.6 MW–3.721 kW_e, 13,016 kW_{th}) is based on the assumptions defined in [28–32]. The duration of construction phase is 2 years, while operating life of the plant is 30 years. The total investment costs are 8,640,856 €, while the operating costs are 4,059,445 €. The price of electricity for all CHP plants using gaseous fuels is 13 c/kWh, thermal energy (3 c/kWh) and wood chips (80 €/t found in [32]). The plant is using 45,000 tons of wood chips per annum and wood chips costs constitute the majority of operating costs. The investment costs for all CHP plants are financed using a 20 years long-term loan, with constant principal, 2 years grace period and 5.5% interest.

The feasibility study for a CHP plant based on gasification from wood is based on data found in [29]. The construction phase takes 2 years and production phase – 30 years. The original plant size is

Table 3
CHP plants using liquid fossil and bio-fuels – basic data.

Parameter	Rape-seed oil	RME	Flash pyrolysis oil	Naphtha
Plant size (gross, MW)	18.6	18.6	18.6	18.6
Electricity (MW_e)	5.58	5.58	5.58	5.58
Thermal (MW_{th})	11.16	11.16	11.16	11.16
Construction (years)	2	2	2	2
Operating life (years)	30	30	30	30
Investment costs (€)	6,582,885.55	6,698,172.78	6,358,034.64	6,316,368.02
Operating costs (€)	7,559,591.96	8,806,361.75	5,106,673.00	4,652,128.00
Fuel consumption (tone/year)	11,741	11,663	29,486	9558
Electricity production (kWh/year)	41,850,000	41,850,000	41,850,000	41,850,000
Thermal power production (kWh/year)	83,700,000	83,700,000	83,700,000	83,700,000
Electricity price	13	13	13	13
Thermal power price (c/kWh)	3	3	3	3

Table 4
Dynamic indicators for CHP plants using liquid biofuels.

Indicator	Rape-seed oil	RME	Flash pyrolysis oil	Naphtha
Net present value (€)	−3,271,339.69	−12,348,708.41	10,544,420.28	13,967,528.66
Internal rate of return (%)	4.37	−119.79	34.17	41.15
Normal payback (years)	17	33	4	3
Dynamic payback (years)	33	33	5	4
Relative NPV	−0.55	−2.08	1.78	2.36
Critical point (years)	18	33	3	3

75 MW_e, which is scaled down to 6.70 MW_e with the heat to power ratio of 1.5 and overall efficiency of 90%. The total investment costs are 10,136,545.70 €, while the operating costs are 4,208,984 € with wood chips costs representing the main part. The plant is using 46,650 tons of wood chips per year.

The feasibility study for a CHP plant based on gasification from coal is based on the same data as for the CHP plant based on gasification from wood. The total investment costs in this case are 9,915,419.58 €, while the operating costs are 1,796,699 € with coal costs representing the main part. The plant is using 29,327 tons of coal per year (45 €/t found in [33]).

The feasibility study for a waste methanization CHP plant is based on data found in [34]. The plant size is scaled up to 18.6 MW with the heat and power efficiency of 58% and heat to power ratio of 1.3. The planed duration of construction is 2 years and operation life is 30 years. The total investment costs are 20,358,425 €, while operating costs are 1,449,000 €. The plant is using 184,650 tons of organic municipal waste per year with a gate fee of 45 €/t [35]. Unlike the other CHP plants where the sales revenue is constituted from selling electricity and thermal power, a large share of sales revenue for waste methanization CHP plant is contributed to the gate fee for organic municipal waste.

The feasibility study for a Combined Cycle Gas Turbine (CCGT) plant is based on data found in [36]. The plant size is 18.6 MW with the heat and power efficiency of 91.3% and heat to power ratio of 0.8. The planed duration of construction is 2 years and operation life is 30 years. The total investment costs are 23,203,046.36 €, while operating costs are 5,412,785 €. The plant is using 13.55 Mm^3 of natural gas with the price of 10 €/GJ [37].

Some basic data from the five feasibility studies for CHP plants using gaseous fossil and bio-fuels are summarized and presented in Table 5.

The dynamic indicators of gaseous fuel CHP production efficiency at 12% discount rate are presented in Table 6. All five CHP plants are economically efficient. It seems that the CHP plant using waste methanization is the most efficient, which is caused by the fact that in this case we do not have fuel costs, but revenues coming from the gate fee for the municipal organic waste. Furthermore, the heat to power ratio for slow pyrolysis CHP plant is 3.5, while for CCGT is 0.8. When we take the same heat to power ratios for all five CHP plants (1.5) then waste methanization CHP plant is the most efficient, followed by gasification from coal, then slow pyrolysis, gasification from wood and the last is CCGT.

From the financial point of view, CHP plants using gaseous fuels generally show better performance than CHP plants using liquid fuels. Hereby, CHP plant based on gasification from coal is the best ranked followed by the CHP plants using gasification from wood, naphtha, flash pyrolysis oil, waste methanization, slow pyrolysis,

Table 5
CHP plants using gaseous fossil and bio-fuels – basic data.

Parameter	Slow pyrolysis	Gasification from wood	Gasification from coal	Waste methan.	CCGT
Plant size (gross, MW)	18.6	18.6	18.6	18.6	18.6
Electricity (MW_e)	3.7	6.7	6.7	4.7	9.3
Thermal (MW_{th})	13.0	10.0	10.0	6.1	7.4
Construction (years)	2	2	2	2	2
Operating life (years)	30	30	30	30	30
Investment costs (€)	8,656,644	10,136,545.70	9,915,419.58	20,358,425	23,203,046
Operating costs (€)	909,445	4,208,984	1,796,699	1,449,000	1,449,000
Fuel consumption	45,000	46,650	29,327	184,650	13.55
Electricity production (kWh/year)	27,907,500	50,220,000	50,220,000	35,250,000	70,049,925
Thermal power production (kWh/year)	97,620,000	75,330,000	75,330,000	45,750,000	57,313,575
Electricity price	13	13	13	13	13
Thermal power price (c/kWh)	3	3	3	3	3

Table 6
Dynamic indicators for CHP plants using liquid biofuels.

Indicator	Slow pyrolysis	Wood	Coal	Waste methan.	CCGT
Net present value (€)	8,301,796	18,369,072	32,643,150	33,263,713	12,221,028
Internal rate of return (%)	22.68	37.72	56.64	23.32	19.49
Normal payback (years)	5	4	3	5	6
Dynamic payback (years)	8	4	3	7	9
Relative NPV	0.98	3.00	3.33	0.81	0.53
Critical point (years)	3	3	3	3	3

natural gas, rape-seed oil and RME. When comparing fossil and bio-fuels, then, with the exception of natural gas, CHP plants using fossil fuels (e.g. coal, naphtha) are better ranked than those using bio-fuels.

5. Appraisal using green accounting standards

Although financial appraisal of various industrial-scale CHP plants provides a good basis for their comparison, it still does not take into account all important factors. One of these factors is related to the environmental protection and the goals of the Kyoto protocol. To conform to these goals the EU has introduced environmental taxes [38] as a set of excise duties. Environmental taxes include energy taxes, transportation taxes and pollution/resource taxes, but only energy taxes and pollution taxes can be applied in our case.

Energy taxes also include the CO_2 taxes and can be applied on CHP plants using different fossil fuels (e.g. naphtha, coal and natural gas). On the other hand pollution taxes can be applied on measured or estimated emissions to air and water, management of solid waste and noise. In our case the pollution taxes can be applied on SO_2 and NO_x emissions. EU has adopted a minimum excise duty for energy taxes for various fossil fuels, but no similar duty has been adopted for the pollution taxes.

To reevaluate the profitability of three CHP plants using fossil fuels (naphtha, coal, natural gas) by taking into account relevant environmental costs ("green accounting") we will use PEGAS (Project Evaluation and Green Accounting System). PEGAS (Fig. 4) is based on Environmental Management Accounting (EMA) [39], UNIDO methodology, which takes into consideration various costs and benefits related to environmental management and protection including waste and emission treatment, prevention and environmental management, material purchase value of non-product output, processing costs on non-product output, environmental incentives, etc.

Regarding the energy taxes we will examine the impacts of minimum excise duty [40] adopted by EU, but also the maximum duty applied in some EU countries on naphtha, coal and natural gas. The minimum excise duty applied on naphtha is 15 €/t, for coal and natural gas – 0.15 €/GJ, while the maximum ones are applied in Denmark, 330.55 €/t for naphtha and 7.84 €/GJ for coal and natural gas.

Minimum excise duty is still not adopted for pollution taxes at the EU level, hence each EU country applies its own taxes. For instance, in France the tax on NO_x is 35 €/t and on SO_2 – 22 €/t [41].

Finally the ash disposal costs vary from country to country based on the average ash haul distance. In case of Canada and the average ash haul distance of 50 km [42] the ash disposal costs are estimated at 0.35 €/MWh.

The estimated environmental taxes and ash disposal costs for CHP plants using naphtha, coal and natural gas are given in Table 7. The estimation has been performed based on the following assumptions: CHP plants are producing annually 502,200 GJ, or

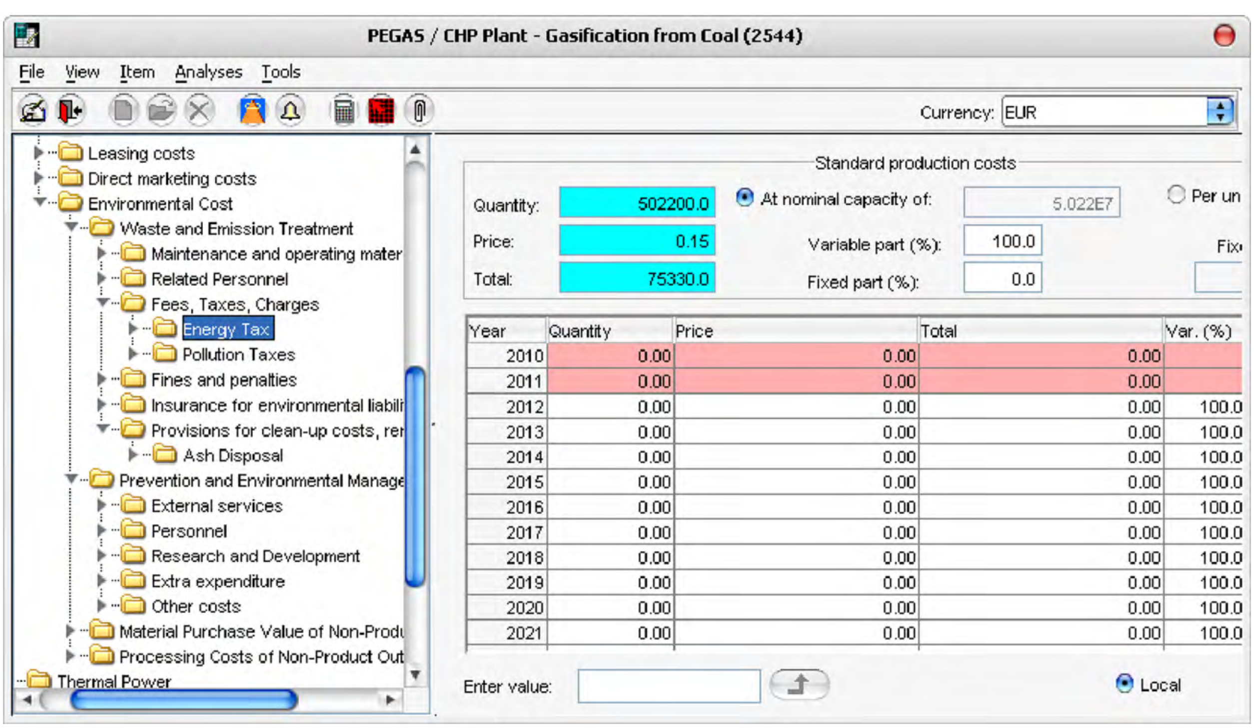


Fig. 4. PEGAS screenshot.

Table 7
Estimated taxes and ash disposal costs for CHP plants using fossil fuels.

	Naphtha	Coal	Natural gas
Energy tax (minimum excise duty)	143,370	75,330	75,330
Energy tax (maximum excise duty)	3,154,140	3,937,248	3,937,248
NO_x tax	742	2651	1045
SO_2 tax	1749	2326	3
Ash disposal costs	n/a	10,264	n/a

Table 8
Dynamic indicators for CHP plants using fossil fuels (minimum excise duty).

	Naphtha	Coal	Natural gas
Net present value (€)	13,113,591.18	32,112,906.08	11,773,876.43
Internal rate of return (%)	39.48	55.97	19.22
Normal payback (years)	4	3	6
Dynamic payback (years)	4	3	9
Relative NPV	2.21	3.27	0.51
Critical point (years)	3	3	3

Table 9
Dynamic indicators for CHP plants using fossil fuels (maximum excise duty).

	Naphtha	Coal	Natural gas
Net present value (€)	−4,758,283.78	9,503,459	−11,062,272.15
Internal rate of return (%)	0.36	25.68	4.53
Normal payback (years)	32	5	17
Dynamic payback (years)	33	6	33
Relative NPV	−0.80	0.97	−0.48
Critical point (years)	23	3	20

139,500,000 kWh and emitting NO_x (naphtha – 0.152 g/kWh, coal – 0.543 g/kWh, natural gas 0.214 g/kWh) and SO_2 (naphtha – 0.570 g/kWh, coal – 0.758 g/kWh, natural gas – 0.001 g/kWh).

Table 8 contains the dynamic indicators for CHP plants using naphtha, coal and natural gas in case of energy tax with minimum excise duty.

The results presented in Table 8 suggest that the application of the minimum excise duty has no effect on the ranking of CHP plants, and it does not stimulate the use of biofuels.

Table 9 represents the dynamic indicators in case of maximum excise duty.

Here the applied energy taxes have substantial impact on the ranking of CHP plants. CHP plant using gasification from wood is now the best ranked followed by the CHP plants using flash pyrolysis oil, gasification from coal, waste methanization, slow pyrolysis, natural gas, rape-seed oil, naphtha and RME. Two CHP plants using biofuels are the best ranked, followed by the gasification from coal, which is still very competitive although very high energy taxes are applied.

6. Demand side effects

The demand side effects represent the focal point of the majority of socio-economic studies, because they are easy to define, and are most important to regional developers and decision makers. The most important demand side impacts are on employment and regional income. They can be divided into:

- Direct effects
- Indirect effects
- Induced effects
- Displacement effects

These effects can be used to represent some economic and social criteria from the socio-economic study:

- Economic gain (net additional profit)
- Income (net additional labor income)
- Economic activity (proportional to net additional income/profit)
- Related industry support (proportional to operating/annualized capital costs excluding labor costs)
- Employment generated (total net additional jobs)
- Avoided rural depopulation (proportional to net additional direct jobs)

The demand side effects will be evaluated on an example of industrial-scale, 18.6 MW CHP plant. Different cases will be analyzed for various liquid and gaseous fuels.

In case of CHP plants using rape-seed oil and biodiesel, the production of rape-seed should be also taken into consideration. For the needs of this analysis, the rape-seed production costs in Germany have been taken into account [19]. The assumed yield is 3.5 t/ha, total variable costs are 1050 €/ha and EU is providing subsidies of 45 €/ha for energy crops. The total area needed for rape-seed production is about 11,000 ha, the total variable costs are 11,550,000 € per year, of which labor costs are approximately 2,887,500 € and equipment and other costs are 8,662,500 €. Taking the agricultural gross wages to be 24,000 €/year, and the turnover/labor ratio for equipment and other costs to be 120,000 €, we come to an estimate of 120.3 direct jobs and 72.2 indirect jobs. There are no displacement jobs, because energy crops can be planted on set aside land.

The net additional labor income (5,053,500 €) can be calculated if the costs for direct (2,887,500 €) and indirect jobs (2,166,000) are summarized. The costs for indirect jobs are taken to be 30,000 € per year. There is no profit in the rape-seed production so to calculate the net additional income/profit (4,558,500 €), from the net additional labor income (5,053,500 €) subsidies (495,000 €) should be subtracted.

The CHP plants using rape-seed oil and biodiesel, are using approximately 12,000 tons of rape-seed oil per year. For each CHP plant, 16 small-scale (750 tons) rape-seed extraction plants are needed. Annualized capital costs are 93,067 of which 9307 € are annualized direct labor costs and 83,760 € are annualized civil works and equipment costs. Labor costs are 333,600 €, and energy costs are 1,950,000 €. Taking that gross wages for rape-seed extraction plant are 24,000 €, for energy production – 30,000 €, and that the turnover/labor ratio is 120,000 €, we get 14.3 direct jobs and 16.9 indirect jobs. The net additional labor income is 840,600 €, average profit is 78,608 € and net additional income/profit is 919,208 €.

The biodiesel CHP plant is using 12,000 tons of biodiesel per year. A biodiesel production plant with 100,000 tons capacity would satisfy the needs of 8.33 biodiesel CHP plants. The annualized value for capital costs is 25,011 €, of which 2501 € for annualized direct labor costs and 22,510 € for annualized civil works and equipment costs. Labor costs are 216,086 €, while energy costs are 483,794 €. Taking that labor costs are 30,000 € and that the turnover/labor ratio is 120,000 €, we get 7.3 direct jobs and 4.2 indirect jobs. The net additional labor income is 342,086 €, average profit is 754,742 € and net additional income/profit is 1,096,828 €.

The liquid biofuel CHP plant has annualized capital costs at 219,430 €, of which 21,943 € are annualized direct labor costs and 197,487 € for annualized civil works and equipment costs. Labor costs are 242,328 €, while material costs are 108,511 €. The gross wages in energy production are 30,000 € and the turnover/labor ratio is 120,000 €, hence we get 8.8 direct jobs and 2.5 indirect jobs. Net additional labor income for rape-seed oil CHP plant is

Table 10
Demand side effects for rape-seed oil CHP plant.

	Rape-seed production	Oil extraction	CHP plant	Total
Operating/annualized capital costs (€)	8,622,500	2,033,760	305,998	10,962,258
Net additional labor income (€)	5,053,500	840,600	317,328	6,211,428
Net additional profit (€)	−495,000	78,608	42,961	−373,431
Net additional income/profit (€)	4,558,500	919,208	360,289	5,837,997
Net additional direct jobs	120.3	14.3	8.8	143.4
Net additional indirect jobs	72.2	16.9	2.5	91.6
Net additional induced jobs	0	0	0	43.8
Total net additional jobs	192.5	31.2	11.3	278.8

Table 11
Demand side effects for biodiesel (RME) CHP plant.

	Rape-seed production	Oil extract.	Biodiesel product.	CHP plant	Total
Operating/annual. capital costs (€)	8,622,500	2,033,760	506,304	292,535	11,455,099
Net additional labor income (€)	5,053,500	840,600	342,086	314,328	6,550,514
Net additional profit (€)	−495,000	78,608	754,742	−1,177,141	−838,791
Net additional income/profit (€)	4,558,500	919,208	1,096,828	−862,813	5,711,723
Net additional direct jobs	120.3	14.3	7.3	8.8	150.7
Net additional indirect jobs	72.2	16.9	4.2	2.4	95.7
Net additional induced jobs	0	0	0	0	42.8
Total net additional jobs	192.5	31.2	11.5	13.0	289.2

317,328 €, average profit is 42,961 € and net additional income/profit is 360,289 €.

The demand side effects for the rape-seed oil CHP plant are given in Table 10. The total additional expenditures retained from additional income/profit, taking that 75% of net additional income/profit is spent domestically, reach 4,378,498 €. If the average turnover/labor ratio is 100,000 €, then we have additional 43.8 induced jobs.

The net additional labor income for the biodiesel (RME) CHP plant is 314,328 €, average profit is – 1,177,141 €, and net additional income/profit is – 862,813 €.

The demand side effects for the biodiesel CHP plant are presented in Table 11. Assuming that 75% of net additional income/profit is spent domestically, total additional expenditures retained from additional income/profit reach 4,283,792 €. If the average turnover/labor ratio is 100,000 €, then we have additional 42.8 induced jobs.

The flash pyrolysis oil CHP plant is using 29,500 tons of flash pyrolysis oil per year. If a plant with the capacity of 2000 tons is used for the production of flash pyrolysis oils, then 14,75 plants are needed for the production of 29,500 tons. The annualized capital costs are 331,580 €, of which 33,158 € for annualized direct labor costs and 298,422 € for annualized civil works and equipment costs. Labor costs are 611,122 €, and energy/material costs are 1,327,721 €. Taking that gross wages are 30,000 €, and that in energy/material production the turnover/labor ratio is 120,000 €, we get 21.5 direct jobs and 13.6 indirect jobs. The net additional labor income is 1,052,280 €, average profit is 1,060,537 € and net additional income/profit is 2,112,817 €.

The net additional labor income for the CHP plant using flash pyrolysis oil is 314,328 €, average profit is 3,359,547 €, and net additional income/profit is 3,673,875 €.

The demand side effects for the flash pyrolysis CHP plant are presented in Table 12. Assuming that 75% of net additional income/profit is spent domestically, total additional expenditures retained from additional income/profit reach 3,626,643 €. If the average turnover/labor ratio is 100,000 €, then we have additional 36.3 induced jobs.

The naphtha-based CHP plant has annualized capital costs at 210,546 €, of which 21,055 € are annualized direct labor costs and 189,491 € for annualized civil works and equipment costs. Labor costs are 242,328 €, while material costs are 108,511 €. The gross wages are 30,000 € and the turnover/labor ratio is 120,000 €, hence we get 8.8 direct jobs and 2.5 indirect jobs. The net additional labor income for the naphtha-based CHP plant is 338,383 €, the average profit is 2,977,092 €, and net additional income/profit is 3,315,475 €. Assuming that 75% of net additional income/profit is spent domestically, total additional expenditures retained from additional income/profit reach 2,486,606 €. If the average turnover/labor ratio is 100,000 €, then we have additional 24.9 induced jobs.

Table 13 gives the summary of the estimated demand side effects for CHP plants using different liquid fossil and bio-fuels. As may be expected, from the national point of view, the most

Table 12
Demand side effects for flash pyrolysis CHP plant.

	Flash pyrolysis oil production	CHP plant	Total
Operating/annualized capital costs (€)	1,626,143	292,535	1,918,678
Net additional labor income (€)	1,052,280	314,328	1,366,608
Net additional profit (€)	1,060,537	2,408,380	3,468,917
Net additional income/profit (€)	2,112,817	2,727,708	4,835,525
Net additional direct jobs	21.5	8.8	30.3
Net additional indirect jobs	13.6	2.4	16.0
Net additional induced jobs	0	0	36.3
Total net additional jobs	32.6	11.2	82.6

Table 13
Total demand side effects for CHP plants using liquid fuels.

	Rape-seed oil	Biodiesel (RME)	Flash pyrol. oil	Naphtha
Operating/annualized capital costs (€)	10,962,258	11,455,099	1,918,678	298,002
Net additional labor income (€)	6,211,428	6,550,514	1,366,608	338,383
Net additional profit (€)	−373,431	−838,791	3,468,917	2,977,092
Net additional income/profit (€)	5,837,997	5,711,723	4,835,525	3,315,475
Net additional direct jobs	143.4	150.7	30.3	8.8
Net additional indirect jobs	91.6	95.7	16.0	2.5
Net additional induced jobs	43.8	42.8	36.3	24.9
Total net additional jobs	278.8	289.2	82.6	36.2

efficient seems to be the combined heat and power production using biodiesel (RME). It shows the best performance according to socio/economic criteria (income, economic activity, related industry support, employment generated, avoided rural depopulation), except for the economic gain where CHP plants using flash pyrolysis oil and naphtha are better. The CHP production using flash pyrolysis oil or naphtha shows better performance than rape-seed oil CHP production concerning economic gain, while rape-seed oil CHP production is better than flash pyrolysis oil or naphtha CHP production in case of income, support of related industry, economic activity, employment generated and avoided rural depopulation. Finally, CHP production based on flash pyrolysis oil is superior to naphtha CHP production according to all estimated socio/economic parameters. These results are actually not surprising, having in mind that CHP plants that use biodiesel require an extensive agricultural production, but also the extraction of rape-seed oil and biodiesel production. Relatively small economic gain in case of rape-seed oil and biodiesel CHP plants is compensated by the large net additional labor income from the labor intensive agricultural production. Even at the present level of electricity (13 c/kWh) and thermal power prices (3 c/kWh), CHP production using liquid biofuels is profitable and, from the national point of view, very attractive.

The CHP plant based on gasification from wood process has annualized capital costs at 337,885 €, of which 33,789 € are annualized direct labor costs and 304,096 € for annualized civil works and equipment costs. Labor costs are 248,517 €, while material/utility costs are 228,467 €. The gross wages are 30,000 € and the turnover/labor ratio is 120,000 €, hence we get 9.4 direct jobs and 4.4 indirect jobs. The net additional labor income for the CHP plant based on gasification from wood process is 414,306 €, the average profit is 4,138,484 €, and net additional income/profit is 4,552,790 €. Assuming that 75% of net additional income/profit is spent domestically, total additional expenditures retained from additional income/profit reach 3,414,593 €. If the average turnover/labor ratio is 100,000 €, then we have additional 34.1 induced jobs.

The CHP plant based on gasification from coal process has annualized capital costs at 330,514 €, of which 33,051 € are annualized direct labor costs and 297,463 € for annualized civil works and equipment costs. Labor costs are 248,517 €, while material/utility costs are 228,467 €. The gross wages are 30,000 € and the turnover/labor ratio is 120,000 €, hence we get 9.4 direct jobs and 4.4 indirect jobs. The net additional labor income for the CHP plant based on gasification from coal process is 413,568 €, the average profit is 6,522,997 €, and net additional income/profit is 6,936,565 €. Assuming that 75% of net additional income/profit is spent domestically, total additional expenditures retained from additional income/profit reach 5,202,423 €. If the average turnover/labor ratio is 100,000 €, then we have additional 52 induced jobs.

The waste methanization CHP plant has annualized capital costs at 1,378,991 €, of which 137,899 € are annualized direct labor costs and 1,241,092 € for annualized civil works and equipment costs. Labor costs are 1,137,889 €, while material costs are 3,190,092 €. The gross wages are 30,000 € and the turnover/labor ratio is 120,000 €, hence we get 37.9 direct jobs and 26.6 indirect jobs. The net additional labor income for the waste methanization CHP plant is 1,935,889 €, the average profit is 9,368,841 €, and net additional income/profit is 11,304,730 €. Assuming that 75% of net additional income/profit is spent domestically, total additional expenditures retained from additional income/profit reach 8,478,548 €. If the average turnover/labor ratio is 100,000 €, then we have additional 84.8 induced jobs.

The slow pyrolysis CHP plant (EDDITh process) has annualized capital costs at 288,028 €, of which 28,803 € are annualized direct labor costs and 259,225 € for annualized civil works and equipment costs. Labor costs are 224,328 €, while material/utility costs are 235,117 €. The gross wages are 30,000 € and the turnover/labor ratio is 120,000 €, hence we get 8.4 direct jobs and 4.1 indirect jobs. The net additional labor income for the slow pyrolysis CHP plant is 376,131 €, the average profit is 3,344,058 €, and net additional income/profit is 3,720,189 €. Assuming that 75% of net additional income/profit is spent domestically, total additional expenditures retained from additional income/profit reach 2,790,142 €. If the average turnover/labor ratio is 100,000 €, then we have additional 27.9 induced jobs.

The Combined Cycle Gas Turbine (CCGT) CHP plant has annualized capital costs at 773,449 €, of which 77,345 € are annualized direct labor costs and 696,104 € for annualized civil works and equipment costs. Labor costs are 190,804 €, while material/utility costs are 199,981 €. The gross wages are 30,000 € and the turnover/labor ratio is 120,000 €, hence we get 8.9 direct jobs and 7.5 indirect jobs. The net additional labor income for the CCGT CHP plant is 415,804 €, the average profit is 4,151,920 €, and net additional income/profit is 4,567,724 €. Assuming that 75% of net additional income/profit is spent domestically, total additional expenditures retained from additional income/profit reach 3,425,793 €. If the average turnover/labor ratio is 100,000 €, then we have additional 34.3 induced jobs.

Table 14 gives a summary of total demand side effects for CHP plants using gaseous fossil and bio-fuels. It is obvious that waste methanization CHP plant is superior according to all parameters to the other four options, which is caused by the fact that instead of heaving biofuel costs, in case of waste methanization, we have income for gate fee. According to all criteria the second best is the gasification from coal process, followed by Combined Cycle Gas Turbine (CCGT – natural gas), gasification from wood and finally slow pyrolysis (EDDITh) process.

Comparing socio/economic parameters of CHP production using liquid and gaseous biofuels, it can be generally said that CHP production using liquid biofuels looks superior to CHP production using gaseous fuels concerning related industry support, income, avoided rural depopulation and in generated employment, while CHP production using liquid biofuels seems better in terms of economic gain and economic activity. On one

Table 14
Total demand side effects for CHP plants using gaseous fuels.

	Wood	Coal	Waste methan.	Slow pyrolysis	CCGT
Operating/annualized capital costs (€)	532,563	525,930	4,431,184	494,342	896,085
Net additional labor income (€)	414,306	413,568	1,935,889	376,131	415,804
Net additional profit (€)	4,138,484	6,522,997	9,368,841	3,344,058	4,151,920
Net additional income/profit (€)	4,552,790	6,936,565	11,304,730	3,720,189	4,567,774
Net additional direct jobs	9.4	9.4	37.9	8.4	8.9
Net additional indirect jobs	4.4	4.4	26.6	4.1	7.5
Net additional induced jobs	34.1	52.0	84.8	27.9	34.3
Total net additional jobs	47.9	65.8	149.3	40.4	60.7

hand, CHP production using gaseous biofuels is very profitable causing high economic activity, while on the other hand, it does not have strong influence on agricultural sector, related industry and employment as CHP production using liquid biofuels has.

When comparing socio/economic parameters of CHP production using fossil and bio-fuels, we can notice that the only important advantage of fossil fuels is in the achieved economic gain (profitability). According to this parameter, naphtha is ranked the second best for liquid fuels, while coal and natural gas are ranked the second and third best for gaseous fuels. However, even this advantage of fossil fuels will probably be diminished soon with the increase of fossil fuel prices.

7. Fuel selection in CHP production

In case when several liquid and gaseous, fossil and bio-fuels are considered for the combined heat and power (CHP) production, it is very important to define a set of criteria that will be used for their comparison and for the selection of the best ones.

The criteria for fuel selection in CHP production can be divided into four main categories:

- Technological
- Financial
- Socio-Economic
- Environmental

The technological criteria are mainly related to fuel properties, and in our case the energy content (LHV expressed in MJ/kg, MJ/t, MJ/m^3) and the non-renewable energy consumed (in J/J of biofuel produced) are the most interesting.

Many static and dynamic criteria can be obtained from the classical financial appraisal of an investment project. FIDES, a tool for the financial appraisal provides 14 static financial parameters (e.g., net profit to equity, long-term debt to net worth, sales to total capital investment, investment to personnel cost, etc.), 5 dynamic parameters (net present value, internal rate of rentability, normal and dynamic payback period, NPV ratio), and 13 risk parameters (e.g., mean NPV and IRR, standard deviation for NPV and IRR, zero risk equivalent, δ-value, etc.).

Various socio-economic studies that discuss the impacts of Renewable Energy Technologies (RET) [43,44] stress different aspects of the complex problem of socio-economic analysis. The methodologies used for the preparation of the socio-economic analysis can be divided into two broad categories qualitative and quantitative. The qualitative methodologies give the description of the main impacts of the technology on the economy and society at different levels (national, regional, local) and can provide subjective socio-economic criteria. On the other hand the quantitative methodologies offer quantified measures for the economic and social impacts. Some of the most popular quantitative methodologies are:

- General equilibrium model [45]
- Cash-flow analysis [16]
- Externality analysis [46]
- Keynesian economic model [47]

There are also many software tools based on these quantitative methodologies for the preparation of socio-economic studies:

- SAFIRE [48]
- ABM [49]
- ELVIRE [50]
- BIOSEM [51]
- INSPIRE [52]
- EXTERNE [53]

However all these quantitative methodologies and software tools are resource intensive in gathering data and used only in projects whose sole task is the preparation of the required socio-economic studies.

The national (regional) economic criteria commonly used in socio-economic studies are: economic gain, incomes, economic activity, related industry support, employment generated, unemployment avoided by the production of biofuel and CHP. Social criteria are: impacts on education and health (mortality, morbidity caused by nitrate and sulfate aerosols), quality of life, avoided rural depopulation, rural diversification and land management.

Having in mind that the quantification of socio-economic parameters is related with extensive efforts and costs needed for gathering the vast quantity of data, in the absence of the quantitative values for the comparison of socio-economic parameters it is possible to use the qualitative values to express their impacts (e.g. 1: VERY HIGH, 2: HIGH, 3: MEDIUM, 4: LOW, 5: VERY LOW).

The environmental criteria [54] include air pollutants (CO_2, CO, NO_x, SO_2, particulates, volatile organic compounds), liquid pollutants (AOX, BOD_5, N, P, COD, inorganic salts), solid wastes (process wastes, ashes, overburden, FGD residuals), biodiversity, visual and noise impacts. The environmental criteria usually include the parameters related with the reduction of greenhouse gases emission, but in case of renewable fuels (such as biofuels) it is considered that they do not produce extra emission of greenhouse gases.

Among various fossil and bio-fuels, for this paper the following liquid fuels used in CHP production have been compared:

- Vegetable oils (rape-seed)
- Esters (Rape-seed Methyl Ester – RME)
- Flash pyrolysis oils
- Naphtha

and the following processes used in CHP production based on gaseous fuels:

Table 15
Criteria parameters for gaseous liquid fuels.

Criterion	Min/Max	Weight	*p*
CO (g/kWh)	Minimized	100	0.50
CO_2 (g/kWh)	Minimized	100	200.00
HC (g/kWh)	Minimized	100	0.50
NO_x (g/kWh)	Minimized	100	1.00
Particulates (g/kWh)	Minimized	80	0.15
SO_2 (g/kWh)	Maximized	100	0.50
Dynamic payback (years)	Maximized	50	10.00
Internal rate of return (%)	Maximized	60	20.00
NPV ratio	Maximized	50	2.00
Net present value	Maximized	60	10,000,000.00
Normal payback (years)	Maximized	40	5.00
Coefficient of variation – IRR (%)	Minimized	20	10.00
Coefficient of variation – NPV (%)	Minimized	20	100.00
Delta value – NPV (%)	Minimized	20	10.00
Interval of variation – IRR (%)	Minimized	20	10.00
Interval of variation – NPV	Minimized	20	5,000,000.00
Mean IRR (%)	Maximized	20	20.00
Mean NPV	Maximized	20	10,000,000.00
Probability threshold – IRR (%)	Minimized	10	10.00
Probability threshold – NPV (%)	Minimized	10	10.00
Standard deviation – IRR (%)	Minimized	20	1.00
Standard deviation – NPV	Minimized	20	500,000.00
Zero risk equivalent – NPV	Maximized	20	10,000,000.00
Current assets to current liabilities	Maximized	10	20.00
Investment to personnel cost	Maximized	10	0.00
Long-term debt to net worth	Minimized	10	2.00
Net cash flow to long-term debt service	Maximized	10	0.00
Net cash flow to long-term liabilities	Maximized	10	0.50
Net cash flow to total sales	Maximized	10	0.50
Net profit + interest to investment (%)	Maximized	10	50.00
Net worth to total liabilities (%)	Maximized	10	50.00
Sales to total capital investment	Maximized	10	0.50
Economic activity	Maximized	100	4,000,000.00
Economic gain	Maximized	100	5,000,000.00
Employment generated	Maximized	90	100.00
Incomes	Maximized	90	4,000,000.00
Related industry support	Maximized	90	7,000,000.00
Avoided rural depopulation	Maximized	80	100.00
Land management	Maximized	50	4.00
Quality of life	Maximized	70	4.00
Rural diversification	Maximized	50	4.00
Availability	Maximized	80	4.00
Energy content (LHV – MJ/kg)	Maximized	30	20.00
Non-renewable energy consumed	Minimized	30	1.00

- Gasification from wood
- Gasification from coal
- Waste methanization
- Slow pyrolysis (EDITTh process)
- Combined Cycle Gas Turbine (CCGT – natural gas)

To these fuels different technological, financial, socio-economic and environmental criteria can be applied in the process of Multi-Criteria Analysis (MCA). However, in practice it proved to be a very difficult task to collect the information about all these criteria, so for the purpose of this paper only criteria presented in Table 17 are used in MCA. For MCA we used the PROMETHEE II method [55] and linear preference function, while specific parameters for each criterion are presented in Table 15.

The criteria values for liquid fuels used for fuel selection in CHP production are given in Table 16, and the values for gaseous fuels are presented in Table 17.

The MCA used in fuel selection for CHP production has been performed using WISE Choice [56]. WISE Choice is an Internet/Intranet application aimed at helping decision-makers to make a desirable choice among different fossil and bio-fuels in CHP production using multiple criteria.

Generally speaking, liquid biofuels show better socio-economic performance than gaseous biofuels, while gaseous biofuels are better in financial criteria. These results are expected because CHP generation using liquid biofuels includes crop and biofuel production, which from one hand enhances socio-economic parameters, but on the other hand increases the costs of CHP production.

The results of Multi-Criteria Analysis (MCA) for CHP production from fossil and bio-fuels using 44 criteria whose parameters are given in Table 17 are presented in Fig. 5. Although the comparison of different fuels in CHP production is performed according to all 44 criteria, this comparison may be unfair, because 26 of them are actually financial parameters (dynamic, static and risk). Therefore financial indicators have a substantial influence on the overall MCA results, and maybe there is no wonder that the CHP production based on gasification from coal and from wood are the best ranked, followed by waste methanization, rape-seed oil, RME, naphtha, natural gas, flash pyrolysis oil and slow pyrolysis. Another observation is that CHP production based on gaseous fuels are generally better ranked (three of them are best ranked), than the CHP production based on liquid fuels.

However, if the number of financial parameters is reduced to a reasonable number (5 dynamic parameters), the ranking will change. Now, thanks to the superior performance regarding socio-economic parameters, CHP production based on two liquid biofuels (rape-seed oil and RME) are better ranked than the three

Table 16
Parameters for liquid fuel selection in CHP production.

Criterion	Rape-seed oil	RME	Flash pyrolysis oil	Naphtha
Technological criteria				
Energy content (LHV – MJ/kg)	37.45	37.70	16.70	44.00
Non-renewable energy consumed	0.55	0.95	1.22	0
Availability	5	3	1	5
Financial criteria				
Static criteria				
Net profit + interest to investment (%)	−1.74	−16.92	38.09	47.88
Net worth to total liabilities (%)	−7.04	−30.37	37.91	44.15
Long-term debt to net worth	12.56	2.11	1.52	1.19
Current assets to current liabilities	1.55	0.42	11.17	17.18
Net cash flow to long-term liabilities	0.05	0.00	0.42	0.51
Net cash flow to long-term debt service	0.42	0.00	3.79	4.63
Sales to total capital investment	1.21	1.19	1.36	1.26
Investment to personnel cost	46.22	47.02	45.25	44.35
Net cash flow to total sales	0.04	−0.12	0.30	0.41
Dynamic criteria				
Net present value	−3,271,339.69	−12,348,708.41	10,544,420.28	13,967,528.66
Internal rate of return (%)	4.37	−119.79	34.17	41.15
Normal payback (years)	17	33	4	3
Dynamic payback (years)	33	33	5	4
NPV ratio	−0.55	−2.08	1.78	2.36
Risk criteria				
Mean NPV	−3,299,045.05	−12,374,808.60	10,568,964.77	13,916,624.26
Standard deviation – NPV	1,939,058.61	2,043,210.39	1,913,142.49	1,617,683.54
Coefficient of variation – NPV (%)	58.78	35.19	18.10	11.62
Interval of variation – NPV	12,988,722.12	14,370,386.77	12,514,110.95	10,611,081.45
Probability threshold – NPV (%)	96.20	99.70	0.00	0.00
Mean IRR (%)	−16.91	−179.64	34.55	41.10
Standard deviation – IRR (%)	627.17	1,802.05	6.00	5.20
Coefficient of variation – IRR (%)	3,708.49	11,446.48	17.35	12.65
Interval of variation – IRR (%)	20,632.27	172,665.99	35.02	31.10
Probability threshold – IRR (%)	95.80	97.20	0.00	0.00
Zero risk equivalent – NPV	−1,000.000	−1,000.000	10,404,295.57	13,827,581.13
Delta value – NPV (%)	69.69	82.78	1.56	0.64
Socio/economic criteria				
Economic criteria				
Economic gain	−373,431	−838,791	3,468,917	2,977,092
Incomes	6,211,428	6,550,514	1,366,608	338,383
Economic activity	5,837,997	5,711,723	4,835,525	3,315,475
Related industry support	10,962,258	11,455,099	1,916,678	298,002
Employment generated	278.8	289.2	82.6	36.2
Social criteria				
Quality of life	1	3	5	1
Avoided rural depopulation	143.4	150.7	30.3	8.8
Rural diversification	5	5	3	1
Land management	5	5	1	1
Environmental criteria				
CO_2 (g/kWh)	150	210	780	256
CO (g/kWh)	0.4389	0.4605	1.0500	0.0517
HC (g/kWh)	0.2710	0.2974	0.9174	0.0107
NO_x (g/kWh)	0.9725	0.9753	1.5080	0.1524
Particulates (g/kWh)	0.0760	0.0760	0.1652	0.0571
SO_2 (g/kWh)	0.4888	0.4895	1.2548	0.5700

best ranked options from the previous ranking (gasification from wood, gasification from coal and waste methanization). They are followed by naphtha, natural gas, flash pyrolysis oil and slow pyrolysis.

If, on the other hand, environmental criteria are excluded from MCA, then we will have another ranking of options. Here CHP production based on waste methanization is ranked the first based on superior financial performance, followed by CHP production based on rape-seed oil and RME, which are the socio/economic champions, and gasification from coal, flash pyrolysis oil, gasification from wood, natural gas, slow pyrolysis and naphtha.

In case when, instead of environmental parameters, socio/economic parameters are excluded from the MCA, we will once more get a different ranking. Again, CHP production based on gaseous fuels become dominant, with three out of four best options (gasification from wood, gasification from coal, naphtha, natural gas). The surprising, third place for the CHP production based on naphtha may be explained by fairly good financial parameters. They are followed then by rapeseed oil, RME, slow pyrolysis, flash pyrolysis oil and waste methanization.

8. Summary of results

Before summarizing the results presented in the previous sections and drawing the conclusions based upon them, it has to be stated once again that the results are only approximate, due to the chronic lack of credible input data. The reasons are threefold: (1) there are no publically available data for real-world, industrial-scale CHP plants using all types of fossil and bio-fuels that can be used for more accurate comparative analysis; (2) there are some publically available data for CHP plants using different liquid and gaseous fuels, but some of them are for small-, other for large-scale plants, so they have to be scaled up or down, which again seriously affects the accuracy of the obtained results; (3) the heat to power

Table 17
Parameters for gaseous fuel selection in CHP production.

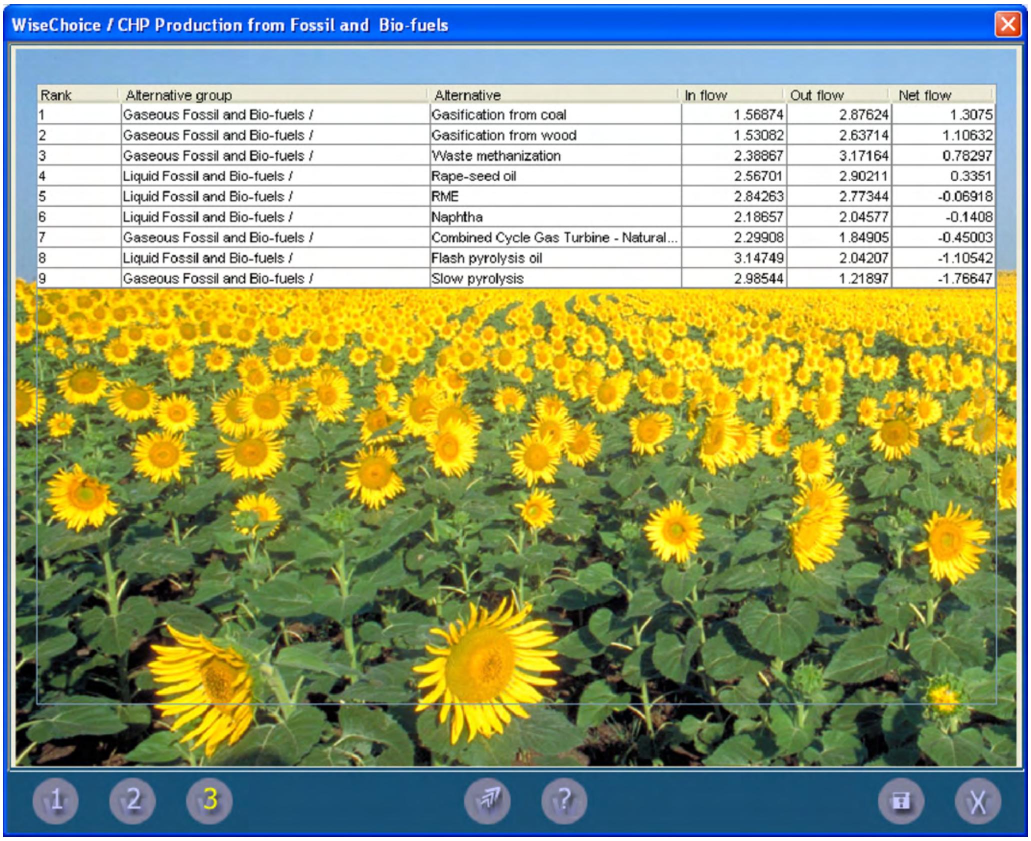
Criterion	Wood	Coal	Waste methaniz.	Slow pyrolysis	CCGT
Technol. criteria					
Energy content (LHV – MJ/kg)	4.75	7.56	18.66	12.22	38.10
Non-renewable energy consumed	0.03	0.00	1.02	0.58	0.00
Availability	5	5	5	5	5
Financial criteria					
Static criteria					
Net profit + interest to investment (%)	40.02	65.24	23.09	64.18	18.33
Net worth to total liabilities (%)	39.15	52.69	26.99	20.68	20.96
Long-term debt to net worth	1.50	0.89	2.69	3.69	3.70
Current assets to current liabilities	25.35	90.27	76.26	11.02	17.11
Net cash flow to long-term liabilities	0.44	0.67	0.30	0.27	0.24
Net cash flow to long-term debt service	3.94	6.07	2.68	2.43	2.21
Sales to total capital investment	0.87	0.89	0.34	0.73	0.47
Investment to personnel cost	50.80	49.95	58.93	62.91	55.03
Net cash flow to total sales	0.52	0.79	0.81	0.36	0.50
Dynamic criteria					
Net present value	18,369,072	32,643,150	33,263,713	8,301,796	12,221,028.43
Internal rate of return (%)	37.72	56.64	23.32	22.68	19.49
Normal payback (years)	4	3	5	5	6
Dynamic payback (years)	4	3	7	8	9
NPV ratio	3.00	3.33	0.81	0.98	0.53
Risk criteria					
Mean NPV	18,382,403	32,620,299	33,326,235	8,008,876	12,262,368.71
Standard deviation – NPV	1,736,862	1,678,757	2,504,101	1,288,069	2,164,354.71
Coefficient of variation – NPV (%)	9.45	5.15	7.51	16.08	17.65
Interval of variation – NPV	9,535,596	9,480,512	14,058,004	8,413,169	12,268,762
Probability threshold – NPV (%)	0.00	0.00	0.00	0.00	0.00
Mean IRR (%)	37.91	56.65	23.38	22.74	19.58
Standard deviation – IRR (%)	3.67	3.81	1.09	2.36	1.59
Coefficient of variation – IRR (%)	9.67	6.73	4.67	10.36	8.13
Interval of variation – IRR (%)	19.44	18.90	6.21	15.42	9.37
Probability threshold – IRR (%)	0.00	0.00	0.00	0.00	0.00
Zero risk equivalent – NPV	18,304,103	32,578,362	33,234,315	7,915,455	12,083,287
Delta value – NPV (%)	0.43	0.13	0.28	1.17	1.46
Socio/economic criteria					
Economic criteria					
Economic gain	4,138,484	6,522,997	9,368,841	3,344,058	4,151,920
Incomes	414,306	413,568	1,935,889	376,131	415,804
Economic activity	4,552,790	6,936,565	11,304,730	3,720,189	4,567,774
Related industry support	532,563	525,930	4,431,184	494,342	896,085
Employment generated	47.9	65.8	149.3	40.4	60.7
Social criteria					
Quality of life	3	3	5	3	3
Avoided rural depopulation	9.4	9.4	37.9	8.4	8.9
Rural diversification	3	1	3	3	1
Land management	1	1	1	1	1
Environmental criteria					
CO_2 (g/kWh)	10	324	270	120	182
CO (g/kWh)	0.0242	0.0399	1.2155	0.9271	0.1703
HC (g/kWh)	0.0036	0.0079	0.6659	0.6645	0.0437
NO_x (g/kWh)	0.5348	0.5430	3.5037	1.9370	0.2137
Particulates (g/kWh)	0.0039	0.0694	0.1834	0.1865	0.0649
SO_2 (g/kWh)	0.9226	0.7582	0.2836	0.0678	0.0010

ratio is different for the analyzed CHP plants (0.8 for CCGT, 2 for liquid fuel CHP plants, 3.5 for slow pyrolysis and 1.5 for all the others), with the direct impact on investment costs and revenues – the lower the heat to power ratio, the higher investment costs and revenues.

However, these results still may be indicative and useful for various stakeholders, because they provide different rankings from different perspectives using some existing standards for financial appraisal, green accounting standards, socio/economic analysis and Multi-Criteria Analysis. The summary of these results is given in Table 18.

The first ranking of CHP plants is produced based on their financial appraisal. Here gasification from coal is the best ranked, followed by gasification from wood, naphtha, flash pyrolysis oil, etc. It seems that coal is still the cheapest fuel for CHP production, while naphtha is also relatively highly ranked (third), despite its high price. The bad profitability results for CCGT plant using natural gas are probably caused by high investment costs, which are caused by low heat to power ratio (0.8). The investment costs for CCGT plant are higher than for waste methanization CHP plant (HP ratio 1.3), two times higher than for the CHP plants based on gasification from wood or coal (HP ratio 1.5), three times higher than for the slow pyrolysis CHP plant (HP ratio 3.5) and even four times higher than for the liquid fuel CHP plants (HP ratio 2). According to financial appraisal CHP plants using rapeseed oil and RME are the lowest ranked, which is caused by the high prices of rapeseed oil and RME and current prices of electricity and thermal power, which are not high enough for a profitable CHP production.

The ranking, which takes into account the green accounting principles, is somewhat different. In case of CHP plants using fossil fuels, it calculates all environmentally relevant costs including the energy and pollution taxes, as well as costs for ash disposal in case of gasification from coal CHP plant. However, it comes out that the pollution taxes applied in the EU countries (e.g. for the emissions of



Rank	Alternative group	Alternative	In flow	Out flow	Net flow
1	Gaseous Fossil and Bio-fuels /	Gasification from coal	1.56874	2.87624	1.3075
2	Gaseous Fossil and Bio-fuels /	Gasification from wood	1.53082	2.63714	1.10632
3	Gaseous Fossil and Bio-fuels /	Waste methanization	2.38867	3.17164	0.78297
4	Liquid Fossil and Bio-fuels /	Rape-seed oil	2.56701	2.90211	0.3351
5	Liquid Fossil and Bio-fuels /	RME	2.84263	2.77344	-0.06918
6	Liquid Fossil and Bio-fuels /	Naphtha	2.18657	2.04577	-0.1408
7	Gaseous Fossil and Bio-fuels /	Combined Cycle Gas Turbine - Natural...	2.29908	1.84905	-0.45003
8	Liquid Fossil and Bio-fuels /	Flash pyrolysis oil	3.14749	2.04207	-1.10542
9	Gaseous Fossil and Bio-fuels /	Slow pyrolysis	2.98544	1.21897	-1.76647

Fig. 5. Results of Multi-Criteria Analysis for liquid and gaseous fuels.

NO_x or SO_2) and the ash disposal costs are negligible comparing to the overall operating costs. The energy taxes, applied as minimum excise duty adopted by the EU, also do not have substantial influence on the profitability of fossil fuel CHP plants. Denmark has the highest energy taxes for the fossil fuels in the EU, and the green accounting results presented in Table 18 are obtained using them. We can see that gasification from coal slipped from the first to the third place, naphtha has fallen from the third to eighth place and is now lower ranked than natural gas (6). The relative ranking of CHP plants using biofuels remained unchanged, where gasification from wood is now the best ranked, followed by CHP plant using flash pyrolysis oil. As a conclusion we may say that energy and pollution taxes in EU should be on a much higher level (e.g. like in Denmark) to be the efficient instruments for the reduction of greenhouse gases emission and air pollution on one side, and to provide a strong support to renewable energy sources and protection of natural capital on the other side. The situation would be even more in favor of renewable energy sources, if EU introduced reasonable incentives for the price of electricity produced using biofuels.

When we approach the problem of ranking CHP plants from the national instead of corporate point of view, i.e. using the socio/economic analysis based on demand side effects, we get a completely different picture. The CHP plants using RME and rapeseed oil are now the absolute champions, followed by the CHP plants using waste methanization and flash pyrolysis oil. The results for the RME and rapeseed oil may not be so surprising, when we now that they require an extensive agricultural production of rapeseed, rapeseed oil extraction and RME production. We may say that CHP production based on RME and rapeseed oil has many positive impacts at the national level regarding economic gain, incomes, economic activity, related industry support, employment generated, quality of life, avoided rural depopulation, rural diversification and land management. However, this production is not profitable from the financial point of view, so policy makers might introduce some incentives for the price of

Table 18
Different rankings for CHP plants using various fossil and bio-fuels.

Rank	Cost-benefit analysis	Green accounting analysis	Socio/economic analysis	MCA			
				All indicat.	Excl. st. and risk	Excl. envir.	Excl. S/E
1	Coal	Wood	RME	Coal	Rape-seed oil	Waste meth.	Wood
2	Wood	f.p. oil	Rape-seed oil	Wood	RME	Rape-seed oil	Coal
3	Naphtha	Coal	Waste meth.	Waste meth.	Wood	RME	Naphtha
4	f.p. oil	Waste meth.	f.p. oil	Rape-seed oil	Coal	Coal	Nat. gas
5	Waste meth.	Slow pyr.	Coal	RME	Waste meth.	f.p. oil	Rape-seed oil
6	Slow pyr.	Natural gas	Nat. gas	Naphtha	Naphtha	Wood	RME
7	Nat. gas	Rape-seed oil	Wood	Nat. gas	Nat. gas	Nat. gas	Slow pyr.
8	Rape-seed oil	Naphtha	Slow pyrolysis	f.p. oil	f.p. oil	Slow pyr.	f.s. oil
9	RME	RME	Naphtha	Slow pyr.	Slow pyr.	Naphtha	Waste meth.

electricity produced by CHP plants using RME or rapeseed oil, to induce the interest of industrial stakeholders for applying these plants in their factories.

Multi-Criteria Analysis (MCA) is also a useful instrument for comparative analysis of different CHP production opportunities, simultaneously taking into account different perspectives of different stakeholders, translating their relative preferences into corresponding criteria/weights selection. Policy makers now have a suitable tool to examine the CHP production using various fossil and bio-fuels and propose the corresponding changes in tax policy or introduce some incentives to support the more extensive use of some (or all) biofuels and to reduce the use of fossil fuels.

To rank CHP plants using various fossil and bio-fuels, we have defined four groups with total of 44 criteria: technological criteria (3), financial criteria (static – 9, dynamic – 5, risk – 12), socio/economic criteria (economic – 5, social – 4) and environmental criteria (6). In this paper we assume that environmental criteria are the most important and have the largest weight (80–100), followed by economic criteria (90–100), social criteria (50–80), dynamic financial criteria (40–60), technological criteria (30–80), risk criteria (10–20) and static financial criteria (10). However, the software tool we have developed is extremely suitable platform for exercising different relative preferences and for performing sensitivity analysis, i.e. to see how different perspectives influence the decision as to the best biofuel for CHP production.

When all criteria are used in the MCA, the best ranked CHP plants are the ones using gasification from coal and from wood. These results are the same as for the financial appraisal ranking. CHP production based on waste methanization, rapeseed oil and RME are now ranked higher than in financial appraisal thanks mainly to socio/economic results. On the other hand due to socio/economic results CHP plants using naphtha, flash pyrolysis oil and slow pyrolysis are now ranked lower than in financial appraisal.

However, if we check the number of criteria in each particular group of criteria, we can notice that financial criteria comprise almost 60% (26 out of 44) of all criteria, so the MCA is heavily biased towards financial standpoint. Therefore, in the second ranking of CHP plants, we excluded static and risk financial parameters in an attempt to provide a more balanced approach to the problem. In this balanced approach CHP plants using rapeseed oil and RME are the best ranked thanks to their superior socio/economic performance and good environmental results. Again good environmental results are the main cause why the CHP plant based on gasification from wood is now ranked higher than the one based on gasification from coal. CHP plant based on waste methanization falls from the third to fifth place, while the ranking of other CHP plant remains unchanged.

When we exclude environmental criteria from MCA, the socio/economic and financial criteria become predominant. The CHP plant using waste methanization profited the most in this situation, because it shows fairly good results in socio/economic and financial domains, while at the same time environmental criteria, where this plant has bad results due to the use of organic municipal waste as a fuel, are now excluded. CHP plants using rapeseed oil and RME are the second and third ranked followed by gasification from coal. CHP plant using naphtha is now the lowest ranked, because it shows poor socio/economic performance.

The final ranking of CHP plants using MCA is produced when instead environmental criteria, socio/economic criteria are excluded. As may be expected CHP plants based on gasification from wood and coal are the best ranked followed by the CHP plants using naphtha and natural gas. Having in mind that socio/economic criteria are excluded from MCA, CHP plants using rapeseed oil and RME are ranked surprisingly high – on the fourth and fifth place. On the other hand CHP plant using waste methanization is expectedly ranked the lowest due to high emissions of greenhouse gases and other air pollutants.

9. Conclusions

The ecosystem has been sending us warning signals (the effects of air and water pollution, climate change, natural capital depletion, etc.) for decades, but because these signals did not have a direct individual impact on the majority of world's inhabitants, we have continued on a path of unsustainable global development. As we push up against the geological limits, the cheap energy that's been driving development since the beginning of the industrial revolution will no longer be either cheap or abundant and we will come face to face with our own unsustainable reality. No combination of known technologies will even come close to filling the gap left by these declining non-renewable energy sources and it will take decades for us to recognize the natural limits to growth of our ecosystem and transition to a steady-state and sustainable economy. Conventional cash-flow analysis used for the appraisal of investment into renewable energy projects, lacks substantial attempts at quantifying the dollar cost to society of pollution-caused or aggravated conditions from the toxic constituents released from the burning of fossil fuels, not to mention complete neglect of cost of depleting non-renewable natural capital. Having the profitability as the crucial concern, this appraisal methodology discourages investment into the renewable energy sources. Therefore, the most important step towards more widespread use of greener energy is to introduce the green accounting standards first into the investment project appraisal and then into every day accounting and financial/economic reporting at both corporate and national level. The example of combined heat and power generation plant powered by biofuel (renewable energy), used in this paper, is rather persuasive, showing how the investors' perspective can change dramatically when the environmental impact is accounted for in investment project appraisal phase.

In this paper we have used standardized methodologies to compare industrial-scale CHP production from different fossil- and bio-fuels. Although these results are only approximate, they still may be indicative and useful for various stakeholders, because they provide different rankings from different perspectives using the existing standards for financial appraisal, green accounting, socio/economic analysis and Multi-Criteria Analysis (MCA).

First we have undertaken twelve investment appraisals using conventional cash-flow analysis and standard UNIDO methodology both for the biofuel production and various cogeneration plants, and ranked them from the investor's viewpoint, where profitability and return of investment comes first. It is no surprise that the CHP plants using fossil fuels are generally better ranked than the ones using biofuels. Then, we have undertaken three appraisals for the CHP plants using fossil fuels (coal, naphtha and natural gas) based on the principles of "green accounting" and it appears that at the present level of minimum excise duty adopted by the EU for energy taxes and applied pollution taxes (France), there is no change in the ranking of CHP plants and no stimulus for broader biofuel use. Only when the maximum values for energy taxes, like those adopted in Denmark, is applied, we get a significant change of ranking in favor of CHP plants using biofuels. This also qualifies our software tool, PEGAS, facilitating investment project appraisal based on "green accounting" principles as a suitable platform for environmentalists and policy makers, to calibrate the instruments used for renewable energy promotion, like environmental taxes, green prices, governmental subsidies, etc.

The paper also analyses demand side effects in nine different cases to assess the socio/economic (national) impacts of CHP plants using different fuels. At the moment, for EU specific circumstances, the CHP plants using Rapeseed Methyl Ester (RME) and rapeseed oil show a superior performance, thanks mainly to the extensive agricultural production in Europe.

Finally, the multi-criteria-analysis has been performed, simultaneously taking into account 44 technological, financial, socio/economic and environmental criteria to rank different fossil and bio-fuels in CHP production. When all 44 criteria are applied, CHP plants using biofuels are generally better ranked than the ones using fossil fuels. However, the majority of criteria used are financial criteria (60%) and when we exclude some of them from MCA to get a balanced number for each group of criteria, then the situation changes even more in favor of CHP plants using biofuels, where the rapeseed oil and RME CHP plants become the best ranked. When environmental criteria are excluded from MCA, CHP plant using waste methanization (as the worst air polluter) become the best ranked. It seems that the socio/economic criteria are very important for CHP plants using biofuels, because when these criteria are excluded from MCA instead of environmental criteria, then CHP plants using gasification from wood is the best ranked, but the next three places are occupied by CHP plants using fossil fuels. We may even say that from the national point of view, CHP production from biofuels is very beneficial.

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